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Division of Cereal and Forage Insects
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INVESTIGATIONS OF THE VARIETAL RESISTANCE OF FIELD CORN TO THE EUROPEAN CORN BORER IN 1937

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The data given in this report were obtained as results of the project for European corn borer research, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. The tests were made near Maumee, Ohio, with supervision from the Federal European corn borer laboratory at Toledo, Ohio, in charge of W. A. Baker. Various Federal and State agencies cooperated by providing the corn seed. J. R. Holbert, formerly of the Bureau of Plant Industry, U. S. Department of Agriculture, Bloomington, Ill., provided 27 of the single and double cross strains; A. A. Bryan, of the Federal Bureau of Plant Industry, Ames, Iowa, provided 16 of the inbred, top-cross, single and double cross strains; A. R. Marston, of the Michigan State Agricultural Experiment Station provided 8 inbreds and hybrids; G. H. Stringfield, of the Ohio State Agricultural Experiment Station provided 5 of the inbreds; Glenn Smith, of the Indiana State Agricultural Experiment Station and Federal Bureau of Plant Industry provided 2 of the inbreds; and G. F. Sprague, of the Federal Bureau of Plant Industry, Columbia, Missouri, C. M. Woodworth, of the Illinois State Agricultural Experiment Station, and the Meyers Hybrid Corn Company each provided one strain. M. T. Jenkins assisted in planning the work and in procuring the seed.

There were four objectives in the work of 1937. First, a series of double crosses involving inbreds Ill. R4, Ill. Hy and Iowa L317B2 in common and one additional inbred were tested to determine the borer resistance of the group compared with the standard borer resistant and borer susceptible strains and to determine the relative borer resistance contributed to the double crosses by the different additional inbreds. This study was based on the fact that inbreds R4, Hy and L317B2 are used in producing some of the outstanding commercial double crosses in the corn belt and that these three inbreds together have contributed material borer resistance in past experiments. Second, the test of promising inbreds was continued. Third, a study was made of the effect of plant maturity on the numbers of borers, their location in the plant and when the reduction in numbers occurred both in the borer-resistant single cross R4 X Hy and the borer-susceptible strain A X Tr. Fourth, a study was initiated in cooperation with J. D. Sayre, corn physiologist, and V. H. Morris, physiological chemist, of the Federal Bureau of Plant Industry and Ohio State Agricultural Experiment Station, to determine, if possible, the plant characters related to corn borer resistance.

Resistance of Double and Single Cross Strains of Field Corn

There were 22 double crosses, 14 single crosses and 1 top cross tested on 8 replications in 1937. Each plot contained 4 hills or a maximum of 12 plants and were planted on May 20. Six egg masses per plant were placed on the plants by hand from July 8 to July 12. The mature or nearly mature borers were dissected from all the plants the latter part of August.

The date of first pollen shedding was recorded for each plant. Ten of the strains shed pollen on the mean date August 1, 9 on the mean date August 2 and 8 on the mean date August 3. Since the mean number of borers per plant from these three groups did not differ more than 0.1 of a borer, no correction to the actual number of borers per plant was made because of differences among the strains in these groups due to differences in stage of plant development.

Of the 22 double crosses 21 involved inbreds Ill. R4, Ill. Hy and Iowa L317B2 in common. The pedigree and number of borers per plant are given in table 1 for each strain within the groups shedding pollen within three days. The remaining strains are given in table 2 with the mean date of first pollen shedding but the borer population in these strains may not be compared with the strains in table 1 because it is not possible to determine how much of the differences in number of borers per plant between the strains in table 1 and those in table 2 might be due to the differences in stage of plant development.

Table 1. - Pedigree of corn varieties and number of European corn borers per plant in double and single cross strains of corn first shedding pollen on the mean dates August 1, 2 and 3, near Toledo, Ohio, 1937.

Field number	Pedigree	Mean number of borers per plant
61	Ill. A X Hy	3.4 ± .21
33	(R4 x Hy) X (Ill. 90 x L317B2)	3.3 ± .21
41	(R4 x Hy) X (Bl. 349 x L317B2)	3.1 ± .25
65	Ill. Hy X Ind. Tr	3.0 ± .20
21	Ill. (R4 x Hy) X (Ill. A x Ind. Tr)	3.0 ± .19
37	(R4 x Hy) X (Ill. A48 x L317B2)	2.8 ± .22
6	Ill. R4 X Ind. Tr	2.8 ± .19
67	Ill. Hy X B.P.I. 540	2.6 ± .19
31	(R4 x Hy) X (Ind. WF9 x L317B2)	2.4 ± .17
1	Ill. R4 X Hy	2.4 ± .17
34	(R4 x Hy) X (B.P.I. 540 x L317B2)	2.4 ± .17
27	Ill. (R4 x Hy) X (Ill. My x L317B2)	2.3 ± .17
13	Ill. R4 X B.P.I. 540	2.2 ± .17
22	Ill. (R4 x Hy) X (Ill. A x L317B2)	2.1 ± .16
35	(R4 x Hy) X (B.P.I. 4-8 x L317B2)	2.1 ± .16
97	Ind. Tr X L317B2	2.1 ± .17
28	Ill. (R4 x Hy) X (Ia. I224 x L317B2)	2.0 ± .15
38	(R4 x Hy) X (Ill. 4211 x L317B2)	2.0 ± .15
40	(R4 x Hy) X (Ia. L289 x L317B2)	2.0 ± .16

Table 1 continued.

Field number	Pedigree	Mean number of borers per plant
29	Ill.(R4 x Hy) X (Ind. Tr x Ia. L317B2)	2.0 ± .16
32	(R4 x Hy) X (I 159 x L317B2)	2.0 ± .16
23	Ill.(R4 x Hy) X (Ill. R4 x L317B2)	1.9 ± .15
66	Ill. Hy X L317B2	1.9 ± .15
39	(R4 x Hy) X (Bl.345B x L317B2)	1.8 ± .15
2	Ill. R4 X Ia. L317B2	1.2 ± .12

Table 2. - Pedigree of corn varieties and number of European corn borers per plant and mean date of first shedding of pollen of double and single cross strains of corn in the 1937 tests near Toledo, Ohio, in addition to those in table 1.

Field number	Pedigree	Mean number of borers per plant	Date of pollen shedding
68	Ill. Hy X Ind. WF9	5.9 ± .45	July 28
81	Ill. A X Ind. Tr	5.0 ± .31	July 30
178	Top-Cross Mich. No. 561	4.0 ± .23	July 30
30	(R4 x Hy) X (I 198 x L317B2)	2.6 ± .18	August 4
117	L317B2 X B.P.I. 540	2.5 ± .19	August 5
25	Ill. (R4 x Hy) X (Mo. K4 x L317B2)	2.2 ± .18	August 7
26	Ill. (R4 x Hy) X (Ill. R98 x L317B2)	2.1 ± .16	August 6
36	(R4 x Hy) X (Ill. 5120 x L317B2)	1.8 ± .15	August 5
110	L317B2 X Kan. Y.S. 56	1.7 ± .16	August 9
24	Ill. (R4 x Hy) X (Mo. Gigas x L317B2)	1.4 ± .12	August 4
111	L317B2 X Mo. K4	1.4 ± .12	August 9

It may be noted from table 2 that single crosses Hy X WF9 and A X Tr and Top-cross Mich. No. 561 gave 5.9, 5.0 and 4.0 borers per plant or about twice as many borers as most of the other strains listed in tables 1 and 2. But these three strains were 2 to 4 days earlier in shedding pollen than the earliest strains in table 1 and it is not known how much of this increase in borers is due to stage of plant development.

It may be noted from table 1 that double crosses Nos. 33, 41 and 21 contained from 3.0 to 3.3 borers per plant. Besides inbreds R4, Hy and L317B2 strains Nos. 33 and 41 involved inbreds Ill. 90 and Bl. 349 as the additional inbred. Inbred 90 is known to transmit borer susceptibility and inbred Bl. 349 is probably in this class. Strain No. 21 is a cross between borer resistant R4 X Hy and standard borer susceptible A X Tr. In this as in other experiments the borer resistance of R4 X Hy is largely lost when it is crossed with A X Tr.

In general it may be concluded from a study of table 1 that the double crosses involving inbreds R4, Hy and L317B2 in common were about as borer resistant as the standard single cross R4 X Hy. It is possible that inbred Bl.345B in addition to inbreds R4, Hy and L317B2 in a double cross gives more borer resistance than R4 X Hy. An average of 1.8 ± .15 borers per plant when Bl.345B is involved is to be compared with 2.4 ± .17, the number of borers in R4 X Hy.

The one outstanding result of the experiment was the low level of borers found in strain No. 2 or R4 x L317B2. The average is 1.2 ± .12 borers per plant compared with 2.4 ± .17 in R4 X Hy. In 7 of the 8 replications the reduction in the number of borers in R4 X L317B2 compared with R4 X Hy ranged from 47.0 to 63.1 percent. Even though these two strains may be compared in but one experiment the consistency of the results between the replications indicates that R4 X L317B2 is the most borer resistant strain so far tested.

Resistance of Inbred Strains of Field Corn

During 1935, 1936 and 1937 a total of 146 inbred strains of corn has been tested for corn borer resistance. To date only 4 of these inbreds may be classed as materially borer resistant.

The 1937 test of 22 inbred strains included 6 strains that showed promise in 1936 or 1935. The 16 other strains were either tested for the first time or were used as standards for comparison .

The 1937 data are the averages of 6 replications planted on May 20. Each plot consisted of 4 hills or a maximum of 12 plants, infested with 3 corn borer egg masses per plant on July 19. The date of pollen shedding of each plant was recorded. No strain shed pollen until 12 days after the eggs hatched. From the regression of the mean number of mature borers per plant on the mean date of pollen shedding the number of borers expected from each strain was estimated. The regression was linear and the availability of the tassels is not considered to be a factor in borer survival in this experiment. The observed and expected numbers of borers and the date of pollen shedding of each strain are given in table 3.

It may be noted from table 3 that inbreds Mich. 77, Ill. R4 and I 205 gave about the same number of borers and were apparently more borer resistant than any other strains. Mich. 77 matured 3.0 borers per plant compared with 4.7 borers, the expected number. Ill. R4 matured an average of 2.9 borers per plant compared with 4.9, the expected number. I 205 matured 3.0 borers per plant compared with 5.4, the expected number. None of the other inbreds had significantly less than the expected number of borers. Inbred L317B2 was latest and showed no borer resistance in this test.

The observed and expected numbers of borers from inbreds Mich. 77, Ill. R4, Iowa I 205 and Iowa L317B2 in the 1935, 1936 and 1937 tests are given in table 4.

Table 3. - Observed and expected numbers of borers per plant found in the inbred strains of corn in the 1937 test. Inbreds Ill. R4 and Hy were given two tests.

Strain	Mean date of pollen shedding	Mean number of borers per plant	
	Days from July 31	Observed	Expected
Ohio 51	0.5	4.3	5.9
Mich. S10	0.6	5.0	5.9
Ind. B2	1.8	5.2	5.7
Ohio 84	2.7	6.3	5.5
Ohio 65	3.4	7.0	5.4
Mich. 241	3.6	4.6	5.4
Mich. 106	3.7	5.8	5.4
Iowa I 205	3.7	3.0	5.4
Ohio 32	3.8	8.7	5.4
Mich. 1450	4.6	5.6	5.2
Ill. Hy	5.0	6.3	5.2
Mich. 275	5.1	5.6	5.1
Ill. Hy	5.5	5.4	5.1
Ohio 56	5.5	4.7	5.1
Ill. R4	6.1	3.2	5.0
K 187	6.3	9.3	5.0
Mich. 2774	6.8	5.3	4.9
I.T.E. 701	7.8	4.2	4.7
Mich. 77	7.8	3.0	4.7
Ill. R4	7.9	2.6	4.7
Ind. Tr	8.4	3.5	4.6
B.P.I. 4-8	9.0	4.3	4.5
Iowa L317B2	11.7	4.7	4.2

Table 4. - Observed and expected numbers of borers per plant found in inbreds Mich. 77, Ill. R4, Iowa I 205 and Iowa L317B2 in 1935, 1936 and 1937.

Year	Inbred strain							
	Mich. 77		Ill. R4		Iowa I 205		Iowa L317B2	
	O	E	O	E	O	E	O	E
1935	4.1	7.0	4.7	6.8	6.2	8.6	3.1	6.7
1936	1.1	5.2	2.4	5.2	3.4	5.4	3.2	5.0
1937	3.0	4.7	2.9	4.9	3.0	5.4	4.7	4.2
Mean	2.7	5.6	3.3	5.6	4.2	6.5	3.7	5.3

As an average of the 3-year tests there was found in the 4 inbreds listed in table 4 an average of 3.48 borers compared with 5.75, the expected number. These 4 inbreds, together with inbreds Mich. 106 and Mich. 2774 were crossed in 1937 with each of 4 inbreds not known to possess borer resistance. Seed of the 24 resulting single crosses is available for testing in 1938 to determine the relative borer resistance of the strains in single cross combination.

Amount of Reduction in Numbers of Borers and When and Where the Reduction Occurs in Borer-Resistant Strain R4 X Hy Compared with Borer-Susceptible Strain A X Tr

For this study 12 plantings were made of each strain from May 7 to June 5. There were 2 plots of each planting, 1 plot being infested with 4 egg masses per plant on July 8 and the other on July 12. Two plants from each plot were dissected every other day to determine the numbers and location of the borers. The two plots of each planting were dissected on alternate days and the dates of dissection were so arranged that the ages of the borers from the two plots were comparable.

In analyzing the data 4 groups of 3 plantings each were made, giving 6-plant samples for each strain at each dissection. The mean numbers of borers per plant were plotted against the dissection dates and free-hand curves were fitted to the plotted data. The numbers of borers as read from the curves are given in table 5 for selected ages. In table 6 are given the ratios between the number of borers found in R4 X Hy and those in A X Tr for corresponding data in table 5.

Table 5. - Numbers of European corn borers in 6 plants of single cross corn strains R4 X Hy and A X Tr according to the date of planting, the date of borer hatch and the age of the borers. The borers resulted from 4 egg masses placed on each plant.

Date of dissection	Age of borers	Plots infested on July 8 — Date of planting — May 7, 10, 12 — Number of borers		May 15, 17, 19 — Number of borers		May 22, 24, 26 — Number of borers		May 29 June 1, 5 — Number of borers		Mean number of borers	
		R4 X Hy	A X Tr	R4 X Hy	A X Tr	R4 X Hy	A X Tr	R4 X Hy	A X Tr	R4 X Hy	A X Tr
July	Days										
9	1	119	131	113	143	114	229	110	78	114	145
10	2	97	109	101	128	88	190	44	68	83	124
11	3	71	89	85	115	55	150	36	57	62	103
12	4	58	77	67	104	40	112	32	49	49	86
14	6	36	58	41	85	30	87	26	39	33	67
18	10	15	39	23	63	23	64	19	29	20	49
21	13	10	31	19	52	20	52	16	24	16	40
26	18	10	23	16	40	17	40	12	19	14	31
August											
4	27	10	19	13	31	15	32	8	15	12	24
9	32	10	19	12	29	15	32	6	15	11	24
13	36	10	19	11	29	15	32	6	14	11	24

Table 5 continued.

Date of dissection	Age of borers	Plots infested on July 12 — Date of planting: May 7, 10, 12 — Number of borers R4 X Hy	A X Tr	May 15, 17, 19 — Number of borers R4 X Hy	A X Tr	May 22, 24, 26 — Number of borers R4 X Hy	A X Tr	May 29 June 1, 5 — Number of borers R4 X Hy	A X Tr	Mean number of borers R4 X Hy	A X Tr
July	Days										
15	3	106	113	131	155	107	94	77	96	105	115
16	4	65	98	107	146	79	70	55	80	77	99
18	6	39	86	39	131	45	57	25	49	37	81
22	10	25	70	25	106	28	41	11	22	22	60
25	13	21	62	23	88	21	36	8	16	18	51
30	18	19	54	21	65	15	30	7	14	16	41
August											
8	27	17	46	20	46	13	28	7	14	14	34
13	32	16	44	19	42	12	27	7	13	14	32
17	36	15	43	18	40	12	26	7	13	13	31
27	46	13	39	16	37	11	25	7	13	12	29
Sept.											
10	60	10	33	14	33	10	22	7	12	10	25

Table 6. - Ratio of the number of European corn borers in field corn hybrid R4 X Hy to those in A X Tr for different plantings, dates of borer hatch and age of borers, near Toledo, Ohio, 1937. The borers resulted from approximately 120 eggs placed by hand on each plant in the samples of 6 plants.

Age of borers	Borers hatched July 8 — Date of planting: May 7, 10, 12	May 15, 17, 19	May 22, 24, 26	May 29 June 1,5	Borers hatched July 12 — Date of planting: May 7, 10, 12	May 15, 17, 19	May 22, 24, 26	May 29 June 1,5	Mean
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	
1	91	79	50	141	--	--	--	--	
2	89	79	46	65	--	--	--	--	
3	80	74	37	63	94	85	114	80	78
4	75	64	36	65	66	73	113	69	70
6	62	48	35	67	45	30	79	51	52
10	38	37	36	66	36	24	68	50	44
13	32	37	38	67	34	26	58	50	43
18	43	40	43	63	35	32	50	50	45
27	53	42	47	53	37	43	46	50	46
32	53	41	47	40	36	45	44	54	45
36	53	38	47	43	35	45	46	54	45
46	53	38	47	43	33	43	44	54	44
60	53	38	47	43	30	42	45	58	45
Mean - 32 to 60 days old	53	39	47	42	34	44	45	55	45

In addition to the 2 plots of each strain of each planting in this study 2 other adjacent plots were grown where the borers were left until nearly mature. The date of first pollen shedding was noted for each plant in these plots. The mean difference between pollen shedding of R4 X Hy and A X Tr decreased at the rate of .071 ± .0267 of a day per day later in planting from 2.8 days on the May 7 planting to 0.7 of a day on the June 5 planting, strain R4 X Hy being the later strain. Thus the large differences in the survival rates could not have been entirely due to differences between the strains in stage of plant development. In this connection a difference in the feeding habits of the newly-hatched borers was observed. On R4 X Hy the feeding areas on the leaves within the whorl were largely about the size of the head of a pin while on A X Tr the areas were relatively elongated. This difference in leaf feeding seems to indicate that the leaves of R4 X Hy are not suitable as food and the larvae made repeated attempts at feeding while on A X Tr they continued feeding at one place indicating a more suitable food.

It may be noted from table 5 that as an average of all the plantings where the borers hatched on July 8 there remained 114 and 145 borers on 6 plants of R4 X Hy and A X Tr, respectively, at the end of the first day after the borers hatched. Since about 720 eggs hatched on these plants these numbers represent a reduction of 84 and 80 percent, respectively, in the number of borers. By the end of the third day the reduction amounted to 91 and 86 percent, respectively, in the plots where the eggs hatched July 8 and 85 and 84 percent where the eggs hatched July 12. The greater reduction on the plots infested on July 8 was probably due to the relatively more immature plants at the time the borers hatched. This relationship has been observed in other experiments.

The reduction in the number of borers in both strains increased with advancing age of the borers but between the third and sixth day the reduction was much greater in R4 X Hy. This fact is brought out by the successively smaller mean numbers of borers with advancing age shown in table 5 and the mean ratios in the last column of table 6. With borers 3, 4 and 6 days in age there were 78, 70 and 52 percent, respectively, as many borers in R4 X Hy as in A X Tr. At 10 days old and after the number in R4 X Hy relative to A X Tr was nearly constant at 45 percent. Evidently the largest part of the differentiation in the number of borers between R4 X Hy and A X Tr takes place within the first 6 days.

During the first 6 days of the larval stage nearly all the borers in both strains were found within the leaf whorl, back of the leaf sheath, under the leaf ligule and on the surface of the plant. The tassels of A X Tr began to be available after the second day and by the sixth day 4 percent of the borers had located there. An average of 28 borers during the first 6 days (table 7) were found under the leaf ligule of A X Tr and 26 under the ligules of R4 X Hy. An average of 9 were on the surface of the plants of both strains. But within the whorl only an average of 144 borers were found in R4 X Hy compared with 264 in A X Tr and back of the leaf sheath 25 borers were found in R4 X Hy and 49 in A X Tr. Since it is within the first 6 days that most of the differentiation in borer survival takes place it is evident that most of the difference between R4 X Hy and A X Tr in the borers surviving can be attributed to the greater number disappearing within the leaf whorl and back of the leaf sheath of R4 X Hy.

Table 7. - Numbers and percentages of European corn borers in different parts of the plant of single cross strains of corn R4 X Hy and A X Tr during the first six days after hatching, near Toledo, Ohio, 1937. Each sample consisted of 18 plants.

Days after hatching	Within whorl		Back of leaf sheath		Under ligule of leaf		On surface of plant		In tassel buds		Total	
Number	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Strain R4 X Hy												
1	245	72.5	49	14.5	27	8.0	17	5.0	0		338	100.0
2	208	73.6	36	12.7	27	9.5	12	4.2	0		283	100.0
3	155	72.0	24	11.2	27	12.6	9	4.2	0		215	100.0
4	115	69.7	17	10.3	26	15.8	7	4.2	0		165	100.0
5	79	63.7	13	10.5	26	21.0	6	4.8	0		124	100.0
6	61	60.3	10	9.9	25	24.8	5	5.0	0		101	100.0
Mean	144	70.6	25	12.3	26	12.7	9	4.4	0		204	100.0
Strain A X Tr												
1	384	78.7	65	13.3	23	4.7	16	3.3	0	0	488	100.0
2	340	78.1	58	13.3	25	5.8	12	2.8	0	0	435	100.0
3	278	75.6	52	14.2	27	7.3	9	2.4	2	0.5	368	100.0
4	244	74.2	46	14.0	29	8.8	7	2.1	3	0.9	329	100.0
5	195	70.4	40	14.4	31	11.2	5	1.8	6	2.2	277	100.0
6	145	64.1	35	15.5	33	14.6	4	1.8	9	4.0	226	100.0
Mean	264	74.8	49	13.9	28	7.9	9	2.5	3	0.9	353	100.0

Determination of Characters Related to Borer Resistance

With the cooperation of Doctors Sayre and Morris, of the Bureau of Plant Industry, U. S. Department of Agriculture, and the Ohio Agricultural Experiment Station, a study is being made of the factors causing Hy X R4 to be borer resistant. For this study a number of pairs of borer resistant, borer susceptible strains of corn are desired. As a preliminary search for clues, single crosses Hy X R4 and A X Tr were grown at Wooster, Ohio, in eight tanks of water in 1937. Five or six plants of each strain were grown in each tank. Fine vigorous plants were grown that appeared normal except for their underdeveloped ears. In four of the tanks the cultural solution was considered normal whereas in the other four tanks the amount of the nutrients in solution was made subnormal. The number of borers per plant and the weight per borer in centigrams are given in table 8.

Table 8. - Number and weight of mature borers from a given number of egg masses hatching on single crosses Hy X R4 and A X Tr growing in water cultures.

Tank number	Hy X R4		A X Tr	
	No. of borers per plant	Wt. per borer (cgms.)	No. of borers per plant	Wt. per borer (cgms.)
4	5.20 ± 1.11	.136	6.83 ± .804	.142
5	1.83 ± .455	.123	6.50 ± .804	.135
9	7.80 ± 1.61	.138	9.20 ± 1.61	.130
10	4.67 ± 1.02	.126	4.50 ± 1.02	.143
Mean	4.88 ± .563	.131	6.76 ± .555	.138
12	4.33 ± 1.02	.138	4.33 ± 1.02	.136
13	1.83 ± .455	.140	5.17 ± 1.02	.145
15	3.67 ± .955	.143	6.60 ± .881	.139
16	2.40 ± .812	.138	8.17 ± 1.47	.128
Mean	3.06 ± .420	.140	6.07 ± .560	.137

The number and weight of borers found in A X Tr from tanks 4 to 10 where the cultural solution was normal was not significantly different from the number and weight of the borers found in the plants from tanks 12 to 16 where nutrients were subnormal. Significantly less borers were found in the plants of Hy X R4 growing in the subnormal solution. In the normal solution 4.88 borers per plant compares with 3.06 borers per plant in the subnormal solution. But the weight of the borers from Hy X R4 from both the normal and subnormal solutions is about the same as the weight of the borers from A X Tr. In field experiments the smaller numbers of borers found in Hy X R4 has been correlated with decreased weights of the borers compared with the numbers and weights of borers found in A X Tr. No interpretation of these data is made at this time.